Renewable Power Sources: Towards a Solar Solution[14]

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Introduction

A comparative study by IEA shows a growth in the energy requirements of 1.7 % per year in the period ranging form 2000 to 2030 [15]; these values represent an increase of 2/3 on the current values. According to this source, above 90% of the energy production in developed countries is, and will continue to be made through non-renewable sources (oil, natural gas and coal). During most of 2005 the price of the oil barrel has been above 44.00 €. On one hand, most specialists recognize that the era of cheap oil has ended, and with it also ends the era of cheap energy produced from fossil fuels. On the other hand the current feasibility studies cannot guarantee the viability of oil in the decades beyond 2030, due the distribution and exhaustion of current oil reserves [16]. As if that weren't enough, since the middle eighties scientists have been warning about the degradation of the environment. Today we can no longer ignore the greenhouse effect. The speculations of the eighties are now a reality. We see glaciers melting, temperatures rising, and many abnormal atmospheric phenomena, extended droughts, massive tropical storms, large hurricanes…

The first steps to control the greenhouse effect have been taken, by the adoption by a large number of countries of the Kyoto protocol and the creation of an international Carbon Dioxide stock market where countries can trade assigned CO_2 levels. So, the shift towards alternative energy production forms is now not only unavoidable but is also becoming a priority. For the solution of this energy deficit, there exists two global recognized solutions: the use of nuclear energy or the use of renewable energy production sources.

The nuclear power solution has many opponents, especially amongst the general population, who tend to adopt a "not in my backyard policy", most people just don't feel comfortable living side-by-side with a nuclear power plant, even if the latest figures for the Chernobyl accident, 19 years later, put the dead too l in 70 causalities, a very low figure compared to other disasters of industrial origin [17]. It is true that nuclear technology has evolved significantly in terms of security and automation of the power plants, but nuclear waste is and will continue to be a reality. We still have to deal with its storing for hundreds of years, putting a burden on generations to come.

A nuclear fusion power plant is at this stage still just a dream. The experimental international power reactor being built in France, (ITER), will not be operational before 2016, even if this is totally successful it will take more than two decades to adapt the technology to commercial use, note that this is a "low" power reactor with a nominal capacity of 500 Mw whose main propose is to be self sustained (i.e. produce enough energy to feed itself). With this last type of central there is no nuclear waste but even the contractors don't expect a fully commercial power plant to be operational before 2050, with a conceptual design starting towards 2025~2030 [18].

Renewable power sources, in the other hand, have a large spectrum of advantages, are readily available, are non-polluting and exist in all of the world countries in one form or another thus avoiding the appearance of cartels as those that exist with the oil producing countries. The key factor for the adoption and expansion of alternative power sources is the kW/h cost. The oil and natural gas costs rise has given a major boost inside many European countries governments to adopt a more decisive renewable energy friendly position. Legislation in these countries now tends to reward and facilitate the implementation of alternative energy power sources. One other favorable factor is the levels of efficiency the latest system possess (i.e. the work necessary to

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[15] *World Energy Outlook 2004*, ISBN 92-64-10817-3 (2004).
[16] IEA, 2005.
[17] Cf. www.scaruffi.com/politics/disaster.html.
[18] www.iter.org/index.htm.

produce one energy unit). This is largely due to the cooperation between the scientific and industrial worlds.
This article will try to give a more or less detailed view of the technology, and the research now taking place. There will only be quoted the most significant projects of each area. The complete description of all of the projects is beyond the scope of this work.

Solar Energy: An Overview

Of all of the sources of renewable energies available one can argue that the most abundant and accessible are solar power, radiation, and the energy of the tides (70 % of the earth surface is covered by water). The tidal wave energy hasn't seen a widespread distribution yet, mainly due to the lack of interest of the governments, most of the coastal areas of the world are exclusive responsibility of the governments, thus not easily open for private venture. Considering solar power, there exist two main fields of application, land based systems and space based systems. The former systems are still in a very embryonic phase, with Japan being the lead researcher in the field, with an experimental satellite-power station to be launched before 2010. Land based systems, on the other hand, are well studied, with major research and application programs in all known forms of solar power production. Given a minimum value of incident radiation, and applying the appropriate system, (i.e. power plant type), for any given area the solar power becomes an income-producing industry.
Looking at the radiation map and taking in account the threshold value of 1900 kWh/m^2/year [19] for yield one can easily see that most "third world", and developing countries have a tremendous potential to become power self-sufficient and even power sellers.

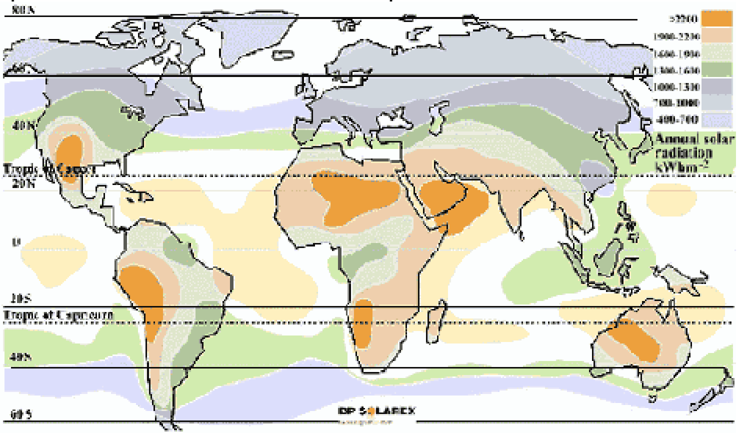

Figure 1: Global Solar Radiation map. *Source*: Sollarmillenium.

Production

There are several methods to transform sunlight to electric power, namely, solar heating and cooling, solar photovoltaics and solar thermal electricity. The later called ***C**oncentrated **S**olar **P**ower* (CSP). Most of the systems described use this later form. The Solar chimney uses the first quoted principle, while the photovoltaic panels use solar photovoltaics. Some of these forms of power production are more efficient than the others, but if we exclude the photovoltaic panels they all have one thing in common: the need for a relatively vast area of ground to be installed on. Making the dry, vast, desert areas with a lot of sun hours and low rainfall found in most sub-developed countries, a very attractive location. In these areas one can maximize the nominal power production output, while minimizing the installation cost due to the low wages practiced.

[19] www.solarmillenium.de →Technology → Parabolic Trough → Advantages.

Concentrated Solar Power

The principle common to this kind of technologies is the use of solar energy to raise the temperature of some king of transfer fluid, which will run turbines which in turn will run electric generators. In areas with high direct sunlight this has proven to be more cost effective than other sunlight power production forms [20]. Also the implementation of the turbine/electric generator is pretty straightforward as the technology is the same for conventional fossil fuel stations.
The main disadvantage of these systems is that they require direct sunlight in order to get an effective temperature raise in the transfer fluid, thus limiting the area of application of such systems.

1. Solar Troughs - These centrals use a filed of parabolic trough shaped mirrors that concentrate sunlight in receiver tubes, heating the transfer fluid, usually some kind of oil, to temperatures close to 400º C. The tubes pass trough a heat exchange system generating superheated steam that will move the turbines. This is probably the most mature solar power production system to date with the first power station installed in the Mojave desert in California in 1985. This central has an installed capacity of 5 x 30 MW [21]. The systems installed in California have been showing an annual efficiency of 14%, that is 4% above equivalent photovoltaic systems [22]. The reliability of the system has been above 90 %.
2. Solar Towers - Here a large number of heliostats are used to focus direct sunlight in a central tower, where the transfer fluid reaches a temperature of 565º C. as the fluid passes trough the heat exchange process its temperature drops to a marginal 290º C. the term "marginal" is used because the fluid is salt which at those temperatures is in liquid state. The most advanced project in this field is currently the *Solar Tres*, taking place in Spain with a termination date occurring in 2006. This project validates critical technologies to enable commercial applications. The next big step in this technology is an ambitious 100 MW tower to be built in South Africa [23].
3. Solar Dishes - Parabolic dish-shaped reflectors concentrate sunlight in two dimensions. This system reaches the highest concentration ratios of all CSP. In the focal point of the dish there is an engine that actuates an asynchronous motor, which in turn produces electric power. A dish with a diameter of 10 meters can produce an output power of 25 kW when exposed to a radiation of 1000 W/m^{2}. The system has efficiency close to 30%, making it the most efficient of all solar systems. Due to the relatively low power output of each dish this system is ideal for isolated settlements and installations with a reasonable power need, (i.e. more than what can be produced by photovoltaic panels). Several dishes have already been connected in grid to supply 5 MW of output power.

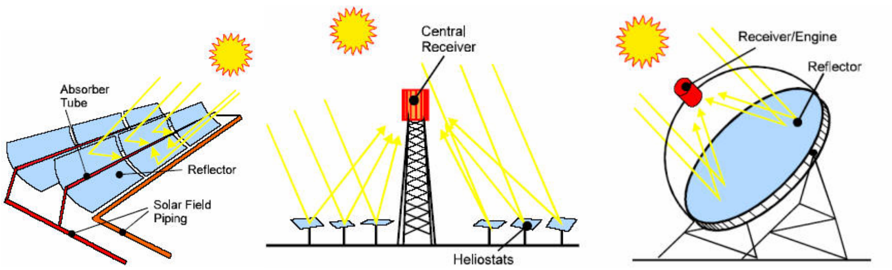

Figure 2: CSP technologies from left to right, solar troughs, solar towers, solar dishes. *Source*: SolarPaces.

Non CSP Systems

1. Photovoltaic Panels - This is the most widespread system of power production from sunlight in use today; it is also the only one that is commercially available at reasonable costs. The power output of each cell is very low, thus they must be connected in series in order to create a useable power output. Each panel is an array of cells, and various panels are usually connected to create the desired power. This system is also dependent on direct sunlight, not on the levels

[20] Cédric Philibert, 2004, 8
[21] www.solarpaces.org/INDITEP.HTM.
[22] www.solarmillenium.de →Technology → Parabolic Trough → Advantages.
[23] www.solarpaces.org

of CSP systems, but the degradation in the power produced with a partially clouded sky is significant. When in operation the cell produces a significant amount of heat that must be cooled, so a water reservoir is connected to the panels, the water cools down the cells and can be used for domestic purposes. The ease of installation of solar panels, the positive side effect of heating up water, and the relatively low investment need to install the system has made it a viable complement (to gird power), for domestic use. The downside of current photovoltaic panels is low conversion efficiency, about 11 %, and still a relatively high cost to developing countries. This last aspect is about to change. The Silicium used currently in photovoltaic cells is of electronic grade, with a purity of 99.99999%. Now the required purity for this type of cell is only 99.999 %, thus much less expensive to produce. By 2006 a prototype of such a panel is expected to be in place. The Silicium used will be PGS, (photovoltaic grade), with a cost of 30 % less than the currently used. So it is expected as the system enters mass production, there will be a cut in prices of the same amount [24].

2. Solar Chimneys - This is probably the most advanced, and the closest to commercial use of all of the solar systems used for industrial power production. The concept behind this structure is quite simple and is well studied. There are three main components involved, the chimney itself, a greenhouse and a wind power turbine.
    a. The collector - This is no more than a greenhouse with a roof of glass or other heat focusing material, with the sides open to let the air pass through it. The collector is placed in a circular shape around a central chimney. The roof is placed to a height of 2 to 6 meters above ground in order to maximize the greenhouse effect. The air is hotter below the glass roof, causing a suction of air in outer border of the collector towards the chimney. This kind of roof lets the short-wavelength sunlight pass through it but traps the long- wavelength radiation emitted by the heated ground, thus maximizing the heating effect on the circulating air. In order to assure a 24h power production period, water filled tubes are placed below ground, so that the heat is accumulated by the water during the day and released during the night, can maintain the necessary air temperature to allow the wind turbine to function during the whole 24h cycle in close to maximum capacity. The collector area for a 200 MW station is in the order of 38 km^2, a 6 to 7 km in radius collector.
    b. The chimney - The chimney itself is the true thermal motor of the central. It is not much more than a pressure tube with low friction losses, calculated to an optimum volume-surface relation. The updraft that the chimney causes in the collector is in direct relation to the air temperature in the collector and the chimney volume. In collectors of large dimensions the temperature may vary in 30º to 35º K. At full load this represents airspeed of 15 m/s, making any maintenance jobs a nuisance. The main problem with the chimney is a logistic one. Its height for a 200 MW output is deemed to be in the range of 1000 meters; although the latest news from the same company point that a better collector technology, with hotter air, can lower the chimney height [25].
    c. The turbine - In this kind of installation the wind turbine used is not of the same class that one can find in normal free-running wind power stations with staged velocity. It uses a cased pressure-staged wind turbo generator, much like the kind of turbines used in hydroelectric power stations. The static pressure is converted to rotational power, with the advantage that the airspeed before and after the turbine is basically unchanged, allowing maintenance work in its vicinity when in operation. Also the power output of this kind of turbine is 8 times greater than its free-running counterparts. The turbine possess variable blade pitch, this regulates the power output according to current airspeed and airflow.

There are currently two commercial programs in development with this technology, both in Australia. The first one calls for a solar chimney with a power of 200 MW to be placed in the Midura desert. This project is in the final phase of the feasibility study. The second one has just recently been announced, and calls for a chimney of 50 MW to be built in a second location in the Australian outback. In both cases the company involved is Enviromission [26]

[24] cf. Sience & Vie, nº1056- September 2005.
[25] www.solarmissiontechnologies.com/project-tower.htm
[26] cf. Jörg Schlaich, Wolfgang Schiel, 2000.

Figure 3: From left to right, solar chimney prototype, solar panels, . *Source*: Solarmilenium and Nrel.

The research on solar power stations

There are a lot of research projects of medium and high output power stations at the moment. If one takes a look at how the research is oriented and funded it becomes clear that every country/region has its own very personal view of the technology and where it should go next. So even if almost all of the high power stations research is based on international cooperation, one can clearly distinguish who does what and where it is done.

Europe (EU)

A real European investigation path, at least in this area is yet to come. That is the goal of the 6th framework program: the creation of a European Research Area (ERA), a flexible and dynamic internal market, with the close interaction of all the EU players at all levels. For this area, renewable energies, a gross total of 890 million € has been assigned (67 million € in the 5th framework program) [27].

Probably the most advanced EU in this field is Spain. It posseses one of the highest solar radiation exposures of Europe, and the institutions have committed themselves to the research. The solar chimney concept was validated in Spain (1982-1989). The main projects occurring today are: *PS10*, *Solar Tres*, *EuroSEGS*, *AndaSol-1* and *2*, and up to 12, 50 Mw parabolic trough plants being implemented by Iberdrola. The government now plans to have installed 500 Mw of solar power by 2010, extended from an initial limit of 200 Mw; the plants of 50 to 100 Mw receive a premium of 18 € cents/Kwh. Also the installation of PV (photovoltaic) panels is strongly advocated by the government.

In Italy the major program is the *Archimedes Project*, a combined cycle/solar trough plant placed in Sicilly.

Portugal seems to have finally woken up. In 2005 it has given the go ahead for a 400 million € PV central to be installed in Amareleja, (Moura). With a nominal capacity of 62 Mw it is claimed to be the largest of its type in the world. The target production of power from this type of energy has been raised from a meager 50 Mw to 150 Mw, additional legislation also obliges new buildings to be energy friendly, whenever possible PV panels must be installed [28].

Germany does not possess the solar radiation levels of Europe's Mediterranean countries, but its government actively supports PV panel installation in households. Also the country's Research and Development is closely involved in all major solar power technologies. All the research in the solar chimney concept and the project of the chimneys to be built in Australia are of German origin. All across Europe research is towards more energy efficient, intelligent buildings and they all incorporate PV technology.

United Sates (USA)

Investigation is coordinated by two major offices: the Energy Efficient and Renewable Energy (EERE), and the National Renewable Energy Laboratory (NREL). Since 1984 there have been installed experimental power plants in California that today account for a grand total of 315 Mw of power production.

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[27] European Distributed Energy projects-6th framework program- KI-NA-21239-EN-C

[28] *Diario de Noticias*, 26 Outubro 2005

Most of NREL investigation is centered around CSP technology: namely to obtain a greater yield from the technology, resolving implementation problems that are occurring in the experimental plants. The main NREL laboratory has 500 scientists, with 146 PhD, 116 MS or MA and 117 BS or BA investigators. Their main projects are: *1.000 MW Initiative*, *Parabolic-trough solar field technology*, *Thermal energy Storage*, all CSP technology related and the *Concentrating photovoltaic (CPV) technology.* This last project hopes to develop PV technology with efficiency close to 40%.
During 2005 the EERE has been supporting 630 projects in diverse fields of renewable energy with a gross value of 1.36 million €. The money is manly focused in R&D with private and university partners. The main collaborators of the Department of Energy, and the EERE are the Sandia National Laboratories and National Renewable Energy Laboratory, the cooperation of those last two gave birth to SunLab, a leading company in the field. Their main projects are: *Solar tres*, *SAIC 25 kW Dish*, *ADDS*, *Nevada 1 MW Solar Dish.* The first project is of international cooperation. The other three are to improve solar dish efficiency, and count on private ventures for support.
The American R&D is supported by institutions with a strong enterprise model where the focus goes to commercially viable projects, with the support of private partners whenever possible. On the other hand there is quasi specialization of the R&D. This occurring almost exclusively in CSP type power stations with some investigations going to photovoltaic (PV).

Japan

Japan is currently the leading world country in solar power with an installed capacity of 635 Mw that is expected to go up to 4820 Mw by 2010 [29]. All of it in the field of photovoltaic panels. The commitment of this country to solar power is noteworthy, as the levels of radiation in Japan are not of the same level as other countries that are lagging behind, *i.e.* Mediterranean countries, USA, Africa, Middle East countries.
All research is coordinated by NewEnergy and Industrial Technology Development Organization (NEDO), established since 1980 as a response to the second oil crisis. All funding for private and public R&D is decided by NEDO, who has a budget of 1,80 thousand million € (250 thousand million ¥), for 2005 alone.
Due largely to the country's morphology and population density the implementation of high output solar power station is impractical. Because of this all research in the field is focused in two main technologies: the PV and solar power satellites. The main projects are: *R&D of a New High-Efficiency Solar Energy Conversion*, *Research on solar power satellite through wireless power transmission*, *Research on an efficient solar power system*, *Study on high-efficiency solar power generation system*. From the funded R&D one can see that Japan has simply dropped all investigation concerning solar energy that's not of the nature referred above. They have left that field to be explored by other countries.
All of the investigation occurring in any field in the country is accessible by the country's scientific database: the READ (Directory Database of Research and Development Activities). This shows the organizational capacity that they have implemented; any relevant information in any given project is stored there and is maintained up-to-date. In this way everybody knows what everyone is doing. So all available resources can be focused with maximum efficiency [30]. Given the actual state of the investigation it is possible to mention some other countries that have chosen, and are actively supporting solar power.

Africa

In Souht Africa, a project of a 100 Mw solar tower is to be made near Cape Town, and it is now in the final study phase. The main private contractor is ESCOM [I].
Algeria plans to be the leading world solar power exporter after 2010, the ISCCS, project. Studies for several CSP stations across the country and the interconnection with the European power grid are in an advance study phase. The major cooperation is coming from German contractors [III].
Two projects in Egypt are occurring at this time. A CSP central in El Nasr, funded by the African Developmental Fund, (1.05 million €), and NERA, (New & Renewable Energy Authority). One being the hybrid solar-fossil fuel station in Kuraymat, with a capacity ranging form 100 to 140 Mw, this

[29] Renewable Energy Development in Japan – NEDO Sptember 2004.
[30] http://read.jst.go.jp/EN/

is the first of a grid of power stations that are expected to be up and running by 2010 with a power output of 750 Mw [III].

Australia

The study of the already mentioned 200 Mw solar chimney is in the final phase. Also during September 2005 the construction of a second 50 Mw Solar chimney was announced. Reports from the contractor company show that more R&D in the collector area could reduce the chimney height or increase the power output.
Other project is the CLFR (Concentrated Line Focus Receiver), a modification of the common CSP stations applying a Fresnel type heat collector, the power output will be 36 Mw and will work together with a coal station. This project is government funded and is actively participated by the Sydney and NSW universities.

First conclusions

Looking at the research, the ever growing involvement of government and, most importantly, the private investment in the field, it is becoming clear that solar power production is about to or, has already obtained, critical mass to enter full scale production.
There seems to be a trend towards international cooperation from the part of most countries in all the major Research and Development programs. Europeans, Americans and Africans seem to be willing to cooperate closely in some technologies such as CSP stations, but do drift apart when it comes to other forms of power production. Noteworthy is that Japan is partially isolated in terms of research. Most of its programs are inside borders, with little cooperation with China, Mongolia, and Korea.
This all could be due to lack of interest from the country in technologies that require a lot of ground to be made functional. Something that they do not possess. Though there are a lot of research projects using CSP technology in a very close-to-commercial advanced state, the fact is that none of them has been adopted in a full commercial form yet. The working stations are all government and other funded, and even if they sell to the power grid, they are all proof of concept stations.
At the moment, and it seems for a couple of years yet, PV is the leading commercial solar production form, with the solar chimney concept right behind. Research must continue and even gain momentum, if this form of power production is to be made a “true” option to traditional and nuclear power alternatives. Any country that fails to realize its power production potential from renewable energy, and fails to act in order to maximize it, could very well suffer decades of very high power costs, with a very high price for the development of that country.
As oil slowly vanishes from our planet stronger measures must be taken to find viable and “green” alternatives and this can only be accomplished by close cooperation and coordinated Research and Development at a global level.

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